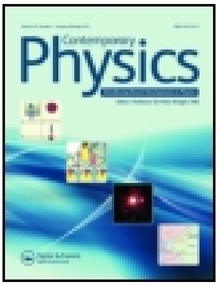

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Operational research: (2) perspective and prologue

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Operational Research: (2) Perspective and Prologue

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SUMMARY. The paper traces the development of Operational Research in industry and university in the period since 1945. It shows the relation between the problem areas of interest, year by year, and current economic and social needs. The paper also shows how the technical methodology developed in a similar manner.

A final section discusses current national problems and the extent to which Operational Research is trying to tackle these.

1. Perspective

This is the second of a pair of papers reviewing the developments which have taken place under the generic heading of operational research. The first paper, by Dr. Stratton, places Operational Research within the historical framework of its conception before the second world war and traces its growth in defence and government in the years since that war. This study will have its beginning in 1946 and will be concerned with industry, commerce, banking and the academic sectors.

It is a truism that O.R. as a discipline has been created out of urgent need and has grown by a combination of scientific methodology, and demonstrated usefulness. We shall at a later stage of this paper place its methodology within a contextual framework of contiguous disciplines, but this will be better demonstrated when the history is developed.

The urgent need in 1946 was clear. The United Kingdom was impoverished. Capital equipment was run down, goods for civilian use were in short supply. The abrupt termination of lend lease left the country with the sudden cessation of a supply of vital imports. But the country was in a good state of morale, and confidence that science and technology could save us in peace time as it had in war was widely shared, almost as a universal faith.

But the scientists, who had been associated with the war time use of O.R., largely went back to their universities and research establishments, a transition from which O.R. suffered for many subsequent years, for there was the serious loss of the first rate brains and of the men whose achievement and maturity would have commanded attention.

But some scientists did move into senior positions in basic industries. The act nationalising the coal industry put on the Board, as of right, a scientist. Sir Charles Ellis the physicist moved from the Army Council to be scientific member of the National Coal Board. Sir Charles Goodeve, metallurgist, moved from the Admiralty to be director of B.I.S.R.A. From these two appointments all else flowed on the industrial front. Ellis created the National Coal Board's scientific department and within it, an O.R. unit. Goodeve not only created an O.R. service within B.I.S.R.A. but since then has remained a dominant figure to whom the O.R. profession owes an incalculable debt.

An address given at the Annual Meeting, at Stirling, of the British Association for the Advancement of Science, September, 1974.

2. The First Problems

In both these basic industries O.R. faced the same difficulties and had the same objectives. The difficulties were partly human—no one knew what O.R. was and there were no trained O.R. staff to be had. They were also partly due to the fact that basic measures were lacking. But the objective was clear, simply to increase production. To this, costs were subservient, as was product quality. Marketing meant allocation and purchasing skills meant cunning in acquiring resources. Production was all. Hence the first studies were basic and were concentrated on the production processes, which fortunately is the most measurable area of industrial activity. But they were also perforce carried out cheek by jowl with work study and hence in those early years every O.R. lecturer had, as his first question, ' What is the difference between O.R. and work study? '—a question which I have not been asked now for 15 years.

As the needs of pure production *per se* became satisfied, other areas, close to it, became the subject of study. Inventory control which allows of simple calculus and probability statistics, became a related topic and control systems for raw materials, in process and finished goods stocks were created. The closely related developments in production scheduling were not yet taking place as the emergence of linear programming had not then occurred (Ackoff and Sasieni).

A natural extension from the production problem was to that of costing. Inventory control theory depends on a number of cost figures, all of which are opportunity costs. It was in this area that the O.R. scientist, brought up within the mainstream of the physical sciences, first found serious problems of measurement. For he discovered that whereas mass, velocity, energy are all definable and measurable for a physical object and moreover, mass, velocity and energy are all independent of the purpose for which the object is going to be used, the cost of producing that object is not uniquely measurable. This cost depends on how the cost will be used. There are always three basic costs, the average cost (which depends on the level of activity), the marginal cost and the opportunity cost (which depends on what else you can get for your money). Within these, there are many variants. Hence the fascination that costing methods have for the O.R. scientist.

As industry became more competitive, emphasis was put on research into productivity and marketing. One of the aspects of productivity is absenteeism and studies were carried out in a spectrum of related topics, absenteeism, disputes, accidents, labour turnover. Initially none of these studies had any behavioural component. Men were looked on as objects; models of labour turnover were mechanistic in terms of age, length of service, travel time to work, and so on. Men, in fact, were looked on as all equal, and as all equally unimportant. (It is interesting to note that of all the frontiers which O.R. has created, that with the behavioural sciences has been the most sensitive.) In this field, the research has been largely that of discovering variables which are related and of then suggesting reasons for the relationship. For example, the relation which shows that as size of hospitals increases so does turnover of nurses, and so also does the length of patient stay. The positive correlations between statistics of accidents, sickness, absenteeism, labour turnover and disputes is another example of this approach to human problems (Tomlinson 1964).

Marketing was found to be even more complex than the human problem. This is an area where controlled experiments are almost impossible, for one's competitors are creating noise which hides any signals that may exist. The amalgam of price, quality, advertising, and product availability is intricate. Even basic hypotheses can be misleading, e.g. lower selling price does not necessarily mean more sales. The temptation here is to create problems that can be solved. For example, advertising agencies spend most of their time agonizing about the theme and presentation of advertisements. This is very subjective. But most models of advertising treat the input simply as the amount of money spent on the advertising, irrespective of its quality. Measurement of output from advertising is sometimes treated in the same simplistic way. Although the purpose of advertising is to sell goods, measuring what is sold in a way that relates these measures to the period in which advertising is taking place is much more difficult. Consequently, recourse is often made to another parameter—the number of people who have seen (or who can remember) the advertisements. When the measures of both cause and effect are viewed through such distorting lenses it is small wonder that modelling in this sector is incomplete. Marketing models are bedevilled by such distortions of measurement. In addition the actual objectives of a marketing campaign may sometimes be cast in a manner that lacks real economic sense but does possess the pseudo virtue of being capable of solution. The field of marketing remains a complex system of complex relationships (Rao).

3. Recent developments

During the last five years two significant developments have taken place, within O.R. The recognition of the human problem has caused questioning of models whose objectives have been solely to maximize profits or minimize costs. It is of course fair to say that only rarely does an organization act in such a way. Qualitative considerations almost always cause profit reduction or cost increase. In addition, unless what is meant by profit is carefully defined, merely to maximize it is a meaningless clarion call. Finally, profits when obtained possess no virtue as such—it is the use to which the profits are devoted that is important. It is surprising how unsophisticated is much thinking on the question of profits. (Only very recently have financial journalists considered inflation when reporting on company progress.) Given the elastic nature of measures of financial well being, it can be seen that consideration of human problems, of such things as the quality of life, is not a simple extension from received knowledge. Here again one is faced with problems of measurement. How does one measure poverty, health care, the effectiveness of a police force, the efficiency of an administrative structure, social well being or propensity to conflict?

The other development has been in the area of finance and banking. Superficially problems in this field are almost trivial, being compounded of only two concepts, time and probability and of one transfer function, money. The translation of a sense of unease into a probability distribution, however, is not straightforward, and the expression of a level of confidence in parametric form causes interesting problems. Given the importance to the nation, of the activities in the City of London, it is a welcome development that most major banks have an O.R. competence (Eilon and Fawkes). The important task

will be to deploy these skills on significant problems and not see them devoted wholly to the routine and the trivial problem. As in advertising, the danger is of casting problems in the form that makes them solvable rather than in a form which reflects reality.

4. Theoretical developments

In parallel with these developments in areas of application there are developments in theory of an equally dynamic nature. In the early years of O.R. there was almost no need for a theoretical underpinning. For the task of theory is threefold. First it has to reveal internal structure. For example, queuing theory is a special approach to the changes in the state of the system by way of introducing transition probabilities from one system state to another. This theory provides an insight into structure. The second task of theory is to act rather like a ladder in a game of snakes and ladders. If certain criteria are satisfied, a theory applies and certain results are immediately produced. The third object of theory is to unify. A theoretical structure which satisfies the first two tasks will also bring together problem areas which are superficially quite different.

The early years of O.R. were those in which painstaking measurement was the main need. Allied with the developments in production already described came the introduction of statistical methods. This very rarely was, nor has it ever been, via the well established theory of experimental design, although at first sight this might have been expected. The problem here is that of control. It is not feasible to preassign levels at which all the various factors can be allowed to operate experimentally. The statistical apparatus initially centred on those methods used in the testing of hypotheses. With the passage of time, more sophisticated techniques have evolved. Reference has already been made to queuing theory, but one of the most important developments has been that of forecasting. The analysis of series of data has been a real topic since the early work of Beveridge on wheat prices (indeed Babylonian astronomers built a whole planetary theory by quite sophisticated statistical analysis of time series data on eclipses and the movement of the stars). The simple extraction of trend and cycle, leading to short term forecasting through various smoothing techniques had led into spectral theory approaches and the methodology of Box and Jenkins (1917). In this field the technical apparatus at the disposal of the O.R. scientist is impressive. In perspective the impact of classical statistical theory on O.R. has been twofold:

(*a*) it has enabled probabilistic forecasts to be derived, and

(*b*) it has provided a metric for testing hypotheses.

On the other hand, formal mathematical methods for dealing with deterministic systems have also made impressive advances. Some 20 years ago the first evolution was made of the methods of linear programming. This is a technique for maximizing (or minimizing) a linear function of a number of variables, where these variables are subject to a number of linear constraints in the form of equalities in inequalities. Originally produced by economists in a major oil company, this technique has probably made most impact in oil production and distribution. Allied to vast computational resources, one oil company has a model of its activities which consists of over 4000 unknown

quantities linked by over 3000 constraints. But these techniques have found usefulness in production scheduling, transportation, product mix and other areas. The mathematics has been extended to deal with non linearities and the special case where the variables have to take only integer values. The applications of this technique have only been possible because of computerization. A sad consequence of all this has been that in one oil company in the U.K., the O.R. group concentrated so much on this one category of problem that eventually all such problems were solved and most of the group were asked to leave.

Perhaps the most interesting technique which is particularly associated with O.R. and which has largely been produced by it, is that of simulation. Simulation involves the imitation of a real situation in such a way that experiments can be carried out in a simulated form. One of the first uses of simulation was in the N.C.B. O.R. group in the early 1950's which simulated the way in which mines could be cleared in an emergency. This involved studies of the performance of underground communications in day to day use and setting up experiments in which the proportion of unanswered calls obtaining in reality are replaced by samples from appropriate statistical distributions in paper and pencil trials. Such simulations allow solutions to be derived in circumstances where actual emergencies cannot be observed and measured. These methods were originally only used where direct mathematical solutions could not be obtained. Hence they were sometimes regarded as a confession of mathematical impotence. The situation is now very different; simulation is an attractive and efficient tool and provides an approach in which the O.R. scientist is acting most closely like his colleagues in the physical sciences (Tocher, and Clapham and Dunn 1957).

5. Academic developments

It was natural that the growth of O.R. in government, industry and commerce should attract consultant services. It is interesting to note that no consultancy offering only O.R. has survived. Large O.R. consultancies do exist but they are allied to other activities, such as accounting, computing and general management. The reason for this is interesting to speculate, but undoubtedly some O.R. scientists have felt uncomfortable in the consultancy profession.

It was not until 1951 that the first lectures in O.R. were given, at University College London. A further five years elapsed before Northampton Polytechnic (now the City University) presented another series. The first university to offer qualifications was Birmingham, with a postgraduate programme. It was only in 1963 that the first chair was created at Lancaster University and since then chairs incorporating 'operational research' into their title have been established in Cambridge, Cardiff, Hull, London, Manchester, Loughborough, Strathclyde, Sussex and Warwick. In all these universities the initial emphasis has been at postgraduate level, but the *realpolitik* of the university situation has forced more teaching into undergraduate courses.

But what is taught? In terms of formal teaching, all courses include coverage of statistical methods and relevant mathematics. This is the core. In addition different universities offer different mixtures of economics, accounting, behavioural science and computing science. Even in postgraduate M.Sc.

courses, it is difficult to find some material which is not already present at undergraduate level somewhere else. The main reason is that relevant material is not universally taught at undergraduate level. It is interesting that students can graduate in science without the least idea of what the statistician means by testing a hypothesis, and what is meant by the scientific method and how it compares to other approaches to decision making.

It is difficult to estimate how many students are currently taking post-graduate courses in O.R., probably of the order of 300, with rather more having some undergraduate teaching. The more difficult aspect of teaching is the practical use of the subject. This is, after all, a practical applied science and to teach its theory without reference to practice is like trying to teach chemistry without letting the student into a laboratory. But here the difficulty is that the O.R. academic does not have a laboratory. Universities have tried to deal with this with varying mixtures of approach ranging from project teams of staff and students offering consultancy services to industry and government, through seconding students to established O.R. groups and down to the study of (sometimes trivial) problems within the university itself. Nowhere is there a university which is satisfied with its solution.

It is in this area of what an O.R. man actually *does* that the greatest need for teaching lies. Much of the absorption of practical problems is on what might formally be called the master-apprentice solution, although in practice it is more likely to resemble the good old industrial training principle of ' standing next to Nelly '. The definition of what is a competent O.R. scientist is a topic which almost tore apart the Operational Research Society.

However, what is emerging is a greater self-consciousness about the model building process which lies at the heart of all good O.R. We now realize that the perception of a problem is subjective. Problems do not exist in reality, they only exist in the mind of the observer. If I say that a certain hospital has a problem in providing the right balance between surgical theatre, pathological laboratory and X-ray facilities, this is only my own perception. Another man might be equally sure that the problem is the rapid turnover of the nurses. We all look at problems in a way which is a personal matter, and select problems for solutions that have been defined in a way which means we are likely to solve them. Probably the root cause is the hierarchy of exercise, example, problem. We are taught from an early age to carry out exercises in which we are rewarded if we give, not the right answer, but the answer teacher wants. Exercises are special cases of examples. But in teaching, the problem is always presented in such a way that the example and the exercise give no option of choice. At the end of a chapter in a mathematics book on, say, bodies falling under gravity we know that no matter how highly disguised the example is, the solution is bound to involve standard equations such as $v = u + at$, etc.

This awful legacy carries over into the practising scientist. The implication is that to every problem, there is a unique ' best ' answer. The problem is always assumed as given. But if the problem is in our minds, then we can see that there is no such thing as an accounting problem or an engineering problem. There are only problems, and we see them all in the light of our own experience. Hence we can never carry out comparative O.R.; if we disagree with one man's research in a particular place, we can never set back the clock and tackle the

problem in our way. Not only that, but as has been said, we will also see the problems differently (Rivett).

6. Prologue

The future is of course an extrapolation of the past. However this is an interesting time to be looking ahead. We must not expect to be solving the same sort of problems in the next decade that we have in the last ten years, this has never applied in the other sciences and there is no reason that it should apply to us. This had undoubtedly worried some O.R. workers. There have been those who have concentrated their minds (and their employers' minds also) so much on, say, production problems that when the main results have been established and the consequences of these results incorporated, they have then found themselves out of work. There are currently a number of O.R. groups where this has happened. O.R. is *research* and it cannot succeed unless it is being constantly presented with problems which at the moment of their posing are insoluble. There are many such problems both within organizations and at a national level. For example—how does one measure customer satisfaction, employee morale? What should be the effort on industrial research and how should it be deployed? How should organizations be controlled so as to achieve their objectives of survival, growth and well being? How do we define the system we are dealing with and how can we classify these systems?

At a national level—we only need to open *The Times* newspaper. The problems have been there for years. Growth, balance of payments, inflation, unemployment, conflict. Can we derive laws as valid as those of physics? For example, could we substantiate the following: " In any society the value of money is the ratio of the total amount of cash and credit to the total amount of goods and services. Hence if any one person receives more money, either

(*a*) others receive less

or (*b*) the value of money declines, unless there is a proportionate increase in total goods and services."

The production and understanding of such laws might do more to achieve economic stability than all our political debates.

At the final analysis therefore we see the unity of O.R. in government, the subject of Dr. Stratton's paper, and of O.R. in commerce and in industry. There are three characteristics. They are:

(*a*) Measurement, rather than emotion as a basis for decision making.

(*b*) The focusing of quantitative human experience in a model, and the use of models to derive general principles.

These are both common to science in general and only reflect the use of science in decision making problems. But the third characteristic is:

(*c*) Relevance. At the risk of being pompous—does the research improve the human situation?

Of these three, measurement, models and relevance, the most important is relevance.

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